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CELL MODULE AND FUEL CONDITIONER DEVELOPMENT

9TH QUARTERLY REPORT: OCTOBER - DECEMBER, 1981

J.M. Feret
Westinghouse Electric Corporation
Advanced Energy Systems Division
Pittsburgh, PA. 15236-0864

January, 1982

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-161

for

U.S. DEPARTMENT OF ENERGY
Energy Technology
Division of Fossil Fuel Utilization
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I. INTRODUCTION

This report is for the second Phase of a six Phase program to develop commercially viable on-site integrated energy systems (OS/IES) using phosphoric acid fuel cell (PAFC) modules to convert fuel to electricity. Phase II is a planned twenty-nine (29) month effort to develop appropriate fuel cell module and fuel conditioner conceptual designs. The fuel cell module development effort involved comprises four coordinated tasks:

Task 1: Design of Large Cell Stacks
Task 2: Stack Fabrication
Task 3: Stack Testing
Task 5: Management Reporting and Documentation

The work accomplished during this reporting period, 10/1/81 thru 12/31/81 inclusive, is described at the subtask level in the following section.

II. TECHNICAL PROGRESS SUMMAY

TASK 1: DESIGN OF LARGE CELL STACKS

1.2 Stack Design

10 kW Stack Design

The 10 kW stack was redesigned to make use of the existing Westinghouse 30 kW Test Facility pressure vessel. This revised design was completed and reviewed by NASA LeRC in a design review meeting held on December 10 and 11, 1981 at Westinghouse Advanced Energy Systems Division. Comments received from NASA and ERC are being evaluated and incorporated into the design as appropriate. Detail drawings for various components of the design were completed and internal discipline review initiated. The highest priority is being placed on the long lead parts such as the molded manifolds.

The cooling and bipolar plate detail drawings were completed and approved for release in the above design review meeting. These drawings were released for die procurement and plate manufacture.

A description of the 10 kW stack design is provided in the following paragraphs. The drawing is not included because of its size and the fact that those in need of it have it as part of the design review package. The stack design requirements were given in the previous quarterly report.

The 10 kW stack design is illustrated in layout drawing 712J943. The stack support and piping arrangement were made compatible with an existing pressure vessel installed in the test facility at AESD. The costs associated with procuring a new vessel have thus been avoided.

Wherever possible, the stack design and piping terminations at the stack were made prototypical of the 4-stack 375 kW module. However, this prototypicality has not been extended beyond the bobbin type connections to the stack which now lead directly into piping weldments connected to the vessel penetrations. The prototypic distribution manifold arrangement, supported

below the stack, used on the earlier design was eliminated to simplify the design, reduce cost, and expedite procurement and assembly.

The stack contains 44 cells in groups of five with two cells at each end of the stack. Each group of five cells is separated by cooling channels. Fuel and process air channels are of the "zee" (Mark II) configuration. Cooling channels are of the "treed" configuration having 28 flow passages at the inlet, which branch into 56 smaller passages at the mid-point of the plate, and, subsequently, into 112 still smaller passages at two-thirds of the distance across the plate. Each set of cooling channels is formed by the mating of two plates, each containing the "treed" passage configuration. The opposite surfaces of each of the two plates contain the "zee" process channel configuration which mate with cell electrodes above and below the cooling plates. The remaining cell components in the 5 cell group are separated by bipolar plates having the "zee" process channel configuration on both sides.

The lower side (cathode interface) of each bipolar plate and the lower side (cathode interface) of each lower cooling plate incorporates an acid groove which supplies the cell matrix with acid. Raised rims are provided along the shim edges of the "zee" channel faces to contain the electrodes. The rim on the lower surface is .022 inches high and the rim on the upper surface is .013 inches high. The matrix is confined to the area inside the shims. The shim in the region of the acid groove extends to the outer edge of the plate and allows the matrix to extend outward over the outer edge of the acid groove to provide support for its outer edge. Shim thickness is varied to accommodate tolerance variations in the electrodes and plate rims, and allow approximately .003 inch compression of the anode and similar compression of the cathode to seal the cell edges.

The cell stack is terminated at each end in a copper collector plate followed by a G-11 insulator plate and carbon steel compression plate. Four stainless steel rods extending the length of the stack and inserted through holes in the edges of the compression plates achieve the required initial clamping pressure of 60 psi on the cells. Teflon tubes around each rod insulates them from the stack. The compression plates, insulator plates, and copper collector

plates are made somewhat wider than the cell plates to accommodate the clamping rod holes and to provide support for the electrical connections at the edges of the collector plates. The compression plates are also made somewhat longer than the insulator and copper collector plates which are the same length as the cell plates, in order to locate the reinforced plastic fluid supply manifolds which are located on the end faces of the stack. A shim plate, made of G-11 material, of the same shape as the insulator plate is provided at the top of the stack to allow the distance between the compression plates to be matched with the overall length of the manifolds while accommodating the overall stack height resulting after compression. Shim plates of several thicknesses will be procured and the required thickness will be achieved by the use of the appropriate combination of these.

The plastic manifolds are made from fiberglass reinforced polyethersulphone and are held in contact with the end faces of the stack by tie rods. Teflon tubing around the tie rods insulates them from the stack. The manifolds are sealed to the faces of the stack by 3/16 inch diameter O-rings made of Viton fluoroelastomer closed cell non-absorbent sponge material. Two O-rings are employed in each manifold, one encircling the fuel cavity and the other the process air cavity. Leaf springs are used to transfer a portion of the tie rod load from the edge of the manifold to its centerline and thus ensure adequate sealing forces on the O-rings in this region of the manifold. The forces transferred from the leaf springs are distributed along the centerline of the manifold via spreader bars.

The plastic manifolds were designed in accordance with comments received from potential molding vendors and as a result employ uniform section thicknesses, unribbed construction, and are capable of utilizing a single-surface molding technique employed by NOW Corporation. This will reduce the tooling costs for short production runs. The single surface molding technique results in an accurately controlled configuration on one side of the component only and a rougher finish on the reverse side. Consistent with this approach, the manifold design confines all critical sealing features to the accurately controlled mold side of the component.

The process gas supply connections to the reinforced plastic manifolds are provided with removable orifices which, in the full module, will be required to ensure good distribution of flow along the length of the stack and between stacks. Flow deflectors are provided between the orifices and the stack to prevent impingement of the orifice jet on local plate flow passages and ensure a well distributed, low velocity, flow of gases into the manifold cavities. The orifice holders are inserted through simple circular holes molded in the manifolds, sealed by fluoroelastomer O-rings and attached by ring nuts. This arrangement eliminates the need for threaded bosses and simplifies the manifold molding. The orifice holders also support a steel mounting plate, provided with studs, to which the supply and return piping elbows are clamped. Simple O-ring seal "bobbin" type connectors are used in the supply and return piping to accommodate thermal expansion motions and misalignment. This type of connection also avoids the application of large wrenching forces to the plastic manifolds during the attachment of the piping.

The stack assembly is supported from the carbon steel bottom support plate which is mounted, in turn, from the cooling air outlet pipe. A plenum box structure and a top plate, made of carbon steel, simulate the presence of the other three stacks in a module. The test stack is sealed to the plenum box structure using a plastic angle component prototypic of the complete module design.

The specification of stainless steel in the orifice and holder details, piping elbows, bobbins, and piping weldments is not necessarily prototypic of the full module. The feasibility of producing these components in an appropriate plastic material for greater cost effectiveness will be investigated. The low pressure differences between the various fluid streams should be easily accommodated by low cost plastic molded components.

The phosphoric acid is supplied to the stack through a 1/4 inch I.D. Teflon hose while in a non-operating condition. The hose is clamped to a machined Teflon connector retained in a drilled hole in the compression plate and sealed to the uppermost cell plate by means of a fluoroelastomer O-ring. Provision is made for shimming at the connector retainer to compensate for variations in the stack shim plate thickness. Excess acid is drained at the bottom of the

stack using a similar arrangement. During operation, the acid supply system is closed to ambient pressure and is internally pressure balanced with the stack.

The electrical connections at the stack consist of copper bars clamped to the copper collector plates with bolts and supported from the G-11 insulator plates. 4/0 nickel-coated copper TFE insulated cable is swaged to the copper connector bars and led to insulated connectors at the pressure vessel penetrations. The cables are supported at intervals along their length to prevent whipping under short circuit fault conditions.

Provision was made in the test facility pressure vessel for instrumentation leads. Three separate penetrations, each of which has the capability of accommodating several multiple lead compression fittings, are provided.

An initial effort was completed to model the stack for mechanical load studies. A 3-D 1/8 volume finite element model was developed for use on the Westinghouse WECAN code. The preliminary results of this effort were discussed at the design review meeting. Additional work is needed in areas such as improving the assumptions, structural representation, and model details before the results can be used and published.

Stack Test Objectives

Test objectives were defined for the stack development tests. These are generally defined as:

- Establish the PAFC fuel cell existing technology base.
- Establish stack performance and operating characteristics for startup, steady-state operating map, and rated conditions, transient performance, and shutdown with operating range of 25-100% rated power conditions.
- Obtain experience to verify processes and test procedures.

An expanded objectives list is presented in Table 1.2-1. Specific objectives are noted in Tables 1.2-2, 1.2-3, and 1.2-4 with the required and desired measurements related to these objectives. The remaining objectives not determinable by direct measurement are listed in Table 1.2-5. Some of these data may be derived from other parameters and this listing helped to provide for such consideration.

10 kW Stack Measurement Requirements Test Plan

Preliminary PAFC 10 kW stack measurement requirements were defined from test objectives and operating constraints to establish the type of measurements and instrumentation needed to accomplish the development test objectives. A preliminary definition of the needed measurements is presented in Table 1.2-6. Some of the related instrumentation requirements for sensors and pertinent comments on specific items are also noted. This table provides a tentative list of the measurements that are needed to accomplish all the stated objectives. It has not been assessed for impact on test operations or evaluated as a function of benefit trade offs. A comprehensive Measurement Requirements List (MRL) giving sensors, instruments, data acquisition requirements and sensor locations will be established and application design specification and sketches prepared to incorporate the instruments in the test assembly.

A tentative test plan for establishing the stack performance characteristics in the region of the rated design operating point and for operating envelope conditions from 25 to 100% rated power was defined. This does not constitute the complete 10 kW stack test plan; only that needed for the performance characterization of the stack. It does, however, constitute the major testing and measurement efforts and indicates the need for approximately 33 tests as a minimum which would require approximately 500 hours of testing. Additional repetition of the test points and endurance testing up to 2000 hours total test time is being considered relative to the test facility availability.

TABLE 1.2-1. PAFC TECHNOLOGY STACK TEST OBJECTIVES

- Establish fuel cell technology base for:
  - stack mechanics
  - manufacturing process, fabrication and quality baseline adequacy
  - technology scale-up to 100 kW stack size, 400 kW modules - performance and endurance characteristics
  - acid management
- Establish Operation Characteristics for:
  - rated conditions
  - start-up and shutdown
  - transients
  - operating range - 25 to 100% rated output power
  - confirmation of design and prediction analytical models
- Establish/Verify Major Constraints for:
  - test procedures
  - design and operating limits
  - endurance

TABLE 1.2-2. MEASUREMENTS FOR STACK MECHANICS

Test Objective	Measurable Variable	Values: Initial	Values: Final	Values: Oper. Cond.
• Establish dimensional characteristics and stability (creep)	• Dimensions	✓	✓	
	• Displacements			✓
	• Loadings	✓	✓	✓
	• Times			✓
• Establish sealing and seal characteristics/ performance	• Leakage rates	✓	✓	
	• Pressure levels	✓	✓	✓
	• Pressure differences	✓	✓	✓
	• Temperature			✓
	• Open circuit voltage	✓	✓	✓
	• Clamping loads	✓	✓	✓
	• Dimensions	✓	✓	
	• Times			✓
• Determine Thermally induced displacements and transient impacts	• Dimensions	✓	✓	
	• Displacements		✓	✓
	• Temperatures			✓
	• Loadings	✓	✓	
	• Times			✓
• Determine flow channel variances and characteristics	• Pressure level			✓
	• Pressure drops			✓
	• Displacements	✓	✓	
	• Dimensions	✓	✓	
• Establish design stresses	• Deflections	✓	✓	✓
	• Loads	✓	✓	

TABLE 1.2-3. MEASUREMENTS FOR PROCESS/FABRICATION CONTROL

Test Objective	Measurable Variable	Values: Initial	Values: Final	Values: Oper. Cond.
• Establish cell to cell uniformity - Accept. Polarization and Life Trends	• Voltage	✓	✓	✓
	• Resistance	✓	✓	✓
	• Corrosion		✓	
	• Catalyst availability	✓	✓	
	• Acid conditions	✓	✓	
	• Reactants - inlet conditions and outlet conditions			✓
	• Times			✓
• Establish stack power	• Current output			✓
	• Voltage output			✓
	• Resistance	✓	✓	✓
	• Pressure			✓
	• Temperature			✓
	• Reactants - inlet conditions and outlet conditions			✓
• Establish Endurance	• Voltage loss	✓	✓	✓
	• Corrosion loss		✓	
	• Catalyst avail. loss	✓	✓	
	• Acid condition	✓	✓	
	• Times			✓

TABLE 1.2-4. MEASUREMENTS TO ESTABLISH OPERATION CHARACTERISTICS

Test Objective	Measurable Variable	Values: Initial	Values: Final	Values: Oper. Cond.
• Establish voltage characteristics and losses	• Stack voltage open cir.	✓	✓	✓
	• Cell voltage open cir.	✓	✓	✓
	• Stack voltage - operating conditions and during transients			✓
• Establish Polarization characteristics (Short and Long Term)	• Cell voltage			✓
	• Current density			✓
	• Pressure			✓
	• Temperature			✓
	• H_2 concentration			✓
	• O_2 concentration			✓
	• CO concentration			✓
	• Resistance	✓	✓	✓
• Establish performance trend data - voltage degradation	• Voltage	✓	✓	✓
	• Current density	✓	✓	✓
	• Time			✓

TABLE 1.2-5. OTHER DESIRED TEST OBJECTIVES*

Determine:

- Reactants Flow Distributions in Stack
- Current Density variation in a cell
- Trickle Leakages - from acid interstitial trackings, service lines, and insulator resistance vagaries
- Acid Distribution in cells
- Seal Effectiveness (Leakage rates)
- Internal, anomalous currents/circuits
- Catalyst Utilization & Effectiveness
- Creep rates
- Corrosion rates
- Heat losses

* Not directly obtainable or measurable

TABLE 1.2-6. PRELIMINARY LIST OF MEASUREMENTS REQUIRED FOR THE 10 kW STACK TESTING

Tentative Req'd Measurements	Tentative Type Sensors	Operating Range Est.	Accuracy
1. Cell Voltage	Individual leads to each plate	-1.0 to +1.5 volt	
2. Cell Current Density	Stack Output amperage	0 to 500 A	
3. Cell Temperature	T/c's in plates	Amb to 220°C	
4. Cell Pressure	Press. Taps-Containment	Amb to 150 psia	
5. Fuel Inlet Pressure	Press. Taps - Manifold	Amb to 150 psia	
6. Oxidant Inlet Pressure	Press. Taps - Manifold	Amb to 150 psia	
7. Coolant Inlet Pressure	Press. Taps - Manifold	Amb to 150 psia	
8. Fuel to Oxidant Press. Diff.	Diff. Press. Leads	-10 to +12" H_2O	
9. Fuel Outlet Pressure	Press. Taps-Manifold	Amb to 150 psia	
10. Oxidant Outlet Pressure	Press. Taps-Manifold	Amb to 150 psia	
11. Coolant Outlet Pressure	Press. Taps-Manifold	Amb to 150 psia	
12. Oxidant Press. Drop	Diff. Press. Leads	-10 to +12" H_2O	
13. Oxidant to Fuel - Exit ΔP	Diff. Press. Leads	-10 to +12" H_2O	
14. Coolant ΔP	Diff. Press. Leads	0 to +12" H_2O	
15. Temp. Difference - Cells	T/C's Distr. in plates	Amb to 220°C	
16. Temp. Difference - Coolant	T/C's in Plenums	Amb to 220°C	
17. Power Level, Transients	Voltage & Amp. of stack circuit	(0 to 12 kW) (time constants)	
18. Cell Internal Resistances	(From Volt. leads)	0 to 1 m Ω	
19. Stack Resistance	(Circuit Resist.)	0 to 40 m Ω	
20. Clamping Load	Strain gages on tie bolts	0 to 100 psi	
21. Stack Compression	Displacement transd. (Distrib.)	+0.1 to -0.1"	
22. Oxidant Utilization	Gas Analyzer - Inlet - Outlet plenums O_2	1.2 to 5 stoichs	
23. Fuel Utilization	Gas Analyzer - Inlet & Outlet Plenums	(tbd)	
24. Oxidant Flow Rate	Flow meters	(tbd)	
25. Fuel Flow Rate	Flow meters	0 to 4 lb/hr	
26. Fuel Leakage	Coolant Outlet Gas Analysis	0 to (tbd - % or ppm)	
27. Stack Creep	Displacements & time	0 to 0.1 in	
28. Acid Additon	Mass added	(tbd)	
29. Acid Loss	Discharge Rate - Outlet Gas Analysis - Outlet	(tbd) (tbd)	
30. Current Leakage	Acid, line, standpipe volt. potentials	(tbd)	
31. H_2O fraction - Exhaust	Humidity - fuel exhaust	0 - 100%	
32. Stack Output Voltage	Circuit Voltage	0 to 50 volts	
33. Stack Output Current	Circuit Amperage	0 to 500 Amps	

1.3 Full Scale Module Design

System Analysis/Trade Studies

Studies to evaluate the effect of pressure and temperature on fuel cell power plant performance and economics were completed. Typical results of cost of electricity (COE) analysis are shown in Figure 1.3-1 for a commercial plant using natural gas at a cost of $\$7/10^6$Btu. The COE is shown as a function of pressure and temperature for projected and fixed fuel cell lifetimes. The fixed lifetime assumption means that the fuel cell system is replaced after five years (30,660 hours at a capacity factor of 70 percent) regardless of the fuel cell operating conditions. The projected lifetime assumption means that the fuel cell system is replaced after a mean of 40,000 hours at operating conditions of 3.4 atm, 190^oC and 325 mA/cm^2. These projected lifetimes were extrapolated from current estimates as a function of the operating conditions. As shown in Figure 1.3-1 the fuel cell operating temperature is a more significant design parameter than pressures for improving the plant economic potential due to a trade-off in fuel cell system performance versus auxiliary system power needs as a function of pressure level. The design operating conditions selected for the prototype plant resulting from these studies are:

190^oC
3.4 atm (50 psia)
$\sim$325 mA/cm^2

A study to evaluate the effect of power level on the cost of electricity was completed. The COE for a commercial plant is shown in Figure 1.3-2 as a function of capacity factor and power level for a fuel cost of $\$7/10^6$ Btu. Below 4.5 MW (12 modules) in plant size, the COE is shown to increase significantly; whereas, above 4.5 MW variation in COE is very gradual. The COE for a 1.5 MW plant is 14% greater than a 7.5 MW plant, and the COE for a 15 MW plant is 3% less than a 7.5 MW plant. Basic conclusions from this study are that there is no

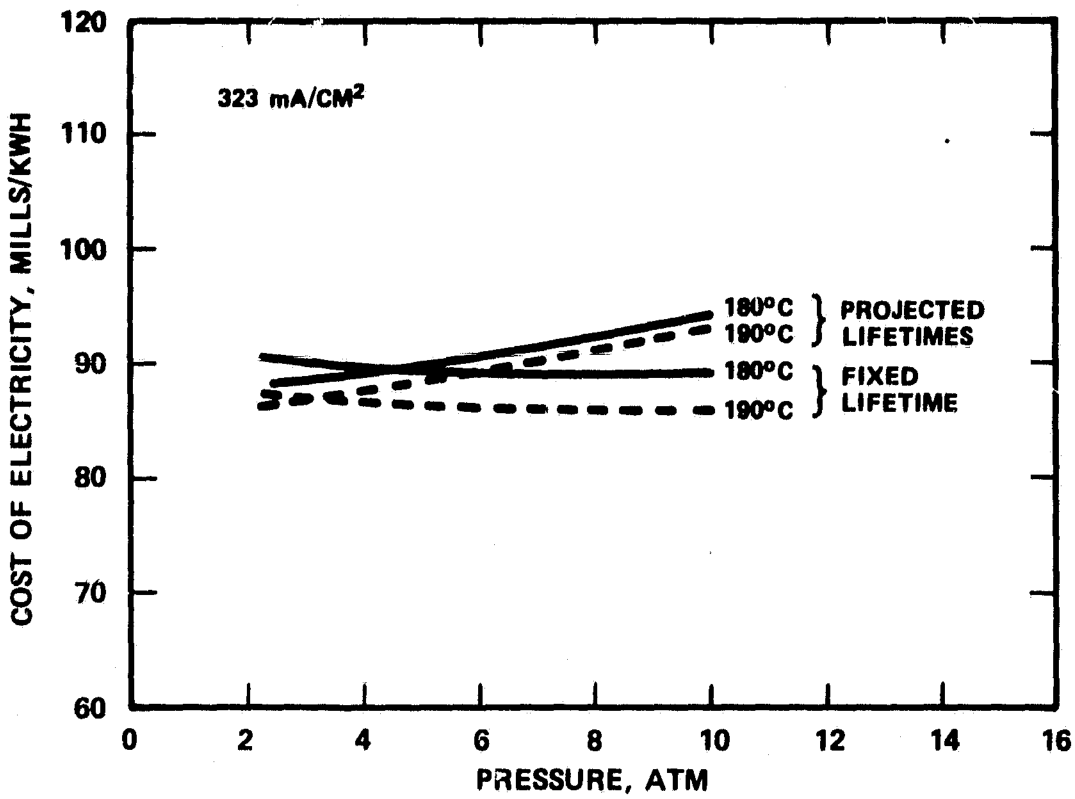


Figure 1.3-1. Non-Integrated, Natural Gas PAFC Utility Power Plant ESEA Results (Non-Levelized) for Projected Commercial Units at 70% Capacity Factor and Fuel Cost of $7/10^6$ Btu

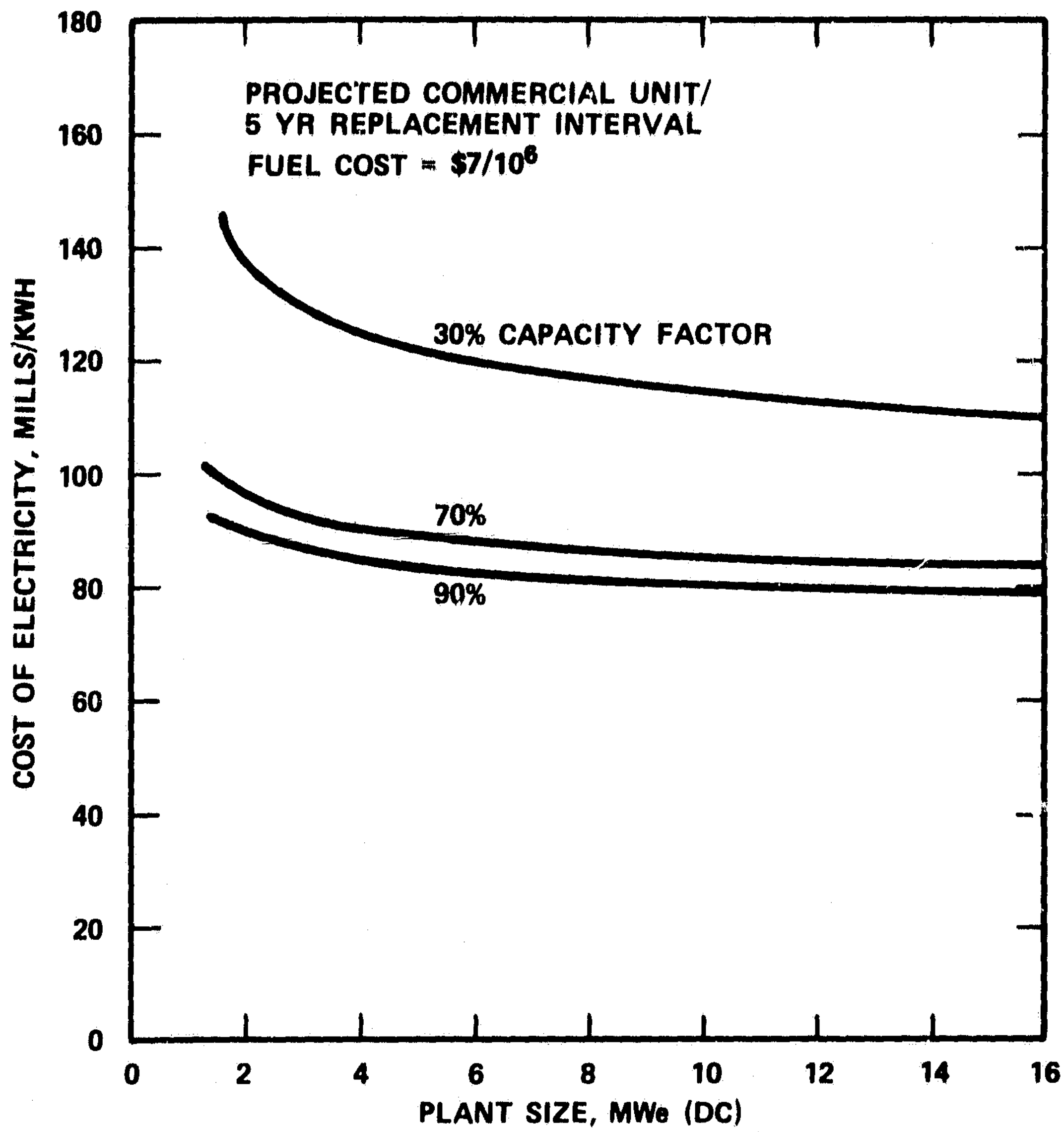


Figure 1.3-2. COE Versus Plant Size and Capacity Factor PAFC Plant, Z-Cell, 190°C, 3.4 Atm, 323 mA/cm^2, Turbine Circulator, Non-Integrated Natural Gas Configuration

economic incentive to change the 7.5 MW size and that sizes below 4.5 MW are not economically desirable for multiple unit applications.

The investigation of various operation and control methods were expanded to consider 6 modes as shown in Table 1.3-1. Factors considered in this investigation were the potential impact of part power operation on cell voltage and lifetime, impact on compressor selection and availability, and impacts on the selection and packaging of the rotating group components. It was concluded that the PAFC plant should be designed for variable fuel cell pressure and temperature operation over the normal operating range. Further work needs to be performed in this area particularly with respect to modes 4, 5, and 6. Several configurations for the rotating equipment were identified as shown in Figure 1.3-3 and associated plant heat rates estimated. The capital costs and COE should be assessed to select a preferred configuration.

Functional Analysis, Requirements Allocation

Functional flow diagrams (FFD's) and requirements allocation sheets were derived for the PAFC utility prototype power plant to a level that has identified the contract end items and overall requirements imposed upon these contract end items. Contract end items are defined as subsystems or equipment groups/units of the overall system that can be broken out as discrete contractual items with acceptable control by specification and where the contractor does not have to iteratively interface with the next higher subsystem to maintain compatibility.

The FFD's as derived down to the third level where some contract end items are identified are illustrated in Figures 1.3-4 through 1.3-8. The preliminary top level requirements allocation sheet is presented in Table 1.3-2.

TASK 2: STACK FABRICATION

2.2 Simulated Stacks

The available ERC fuel cell stack sub-assembly and assembly procedures were updated based upon observing the assembly of stack 564 at ERC and our own

TABLE 1.3-1. POWER CONTROL MODES

MODE	PRESSURE	AVERAGE CELL TEMPERATURE	AIR COOLANT EXIT TEMPERATURE	PHOSPHORIC ACID CONCENTRATION	ESTIMATED RELATIVE CELL LIFE WITH POWER RATIO OF 0.7 AT RATED POWER	ESTIMATED RELATIVE CELL LIFE WITH POWER RATIO OF 0.25 AT RATED POWER
1	Constant	Constant	Variable	Constant	0.8	0.6
2	Constant	Variable	Constant	Variable	0.8	0.7
3	Variable	Constant	Variable	Variable	1.0	0.5
4	Variable	Variable	Constant	Variable	1.0	1.3
5	Variable	Variable	Constant	Constant	1.1	1.9
6	Variable	Variable	Variable	Constant	1.3	2.1

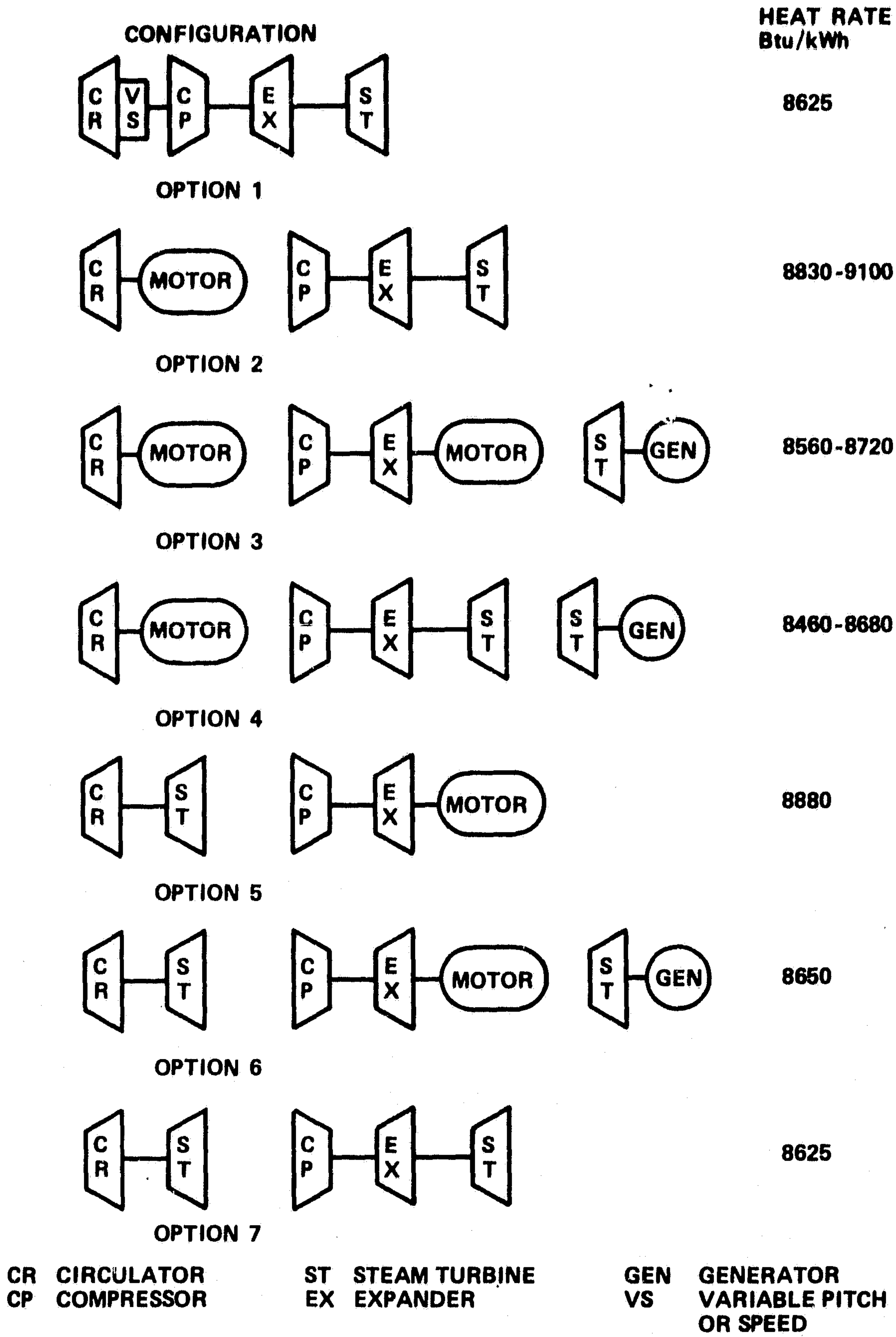
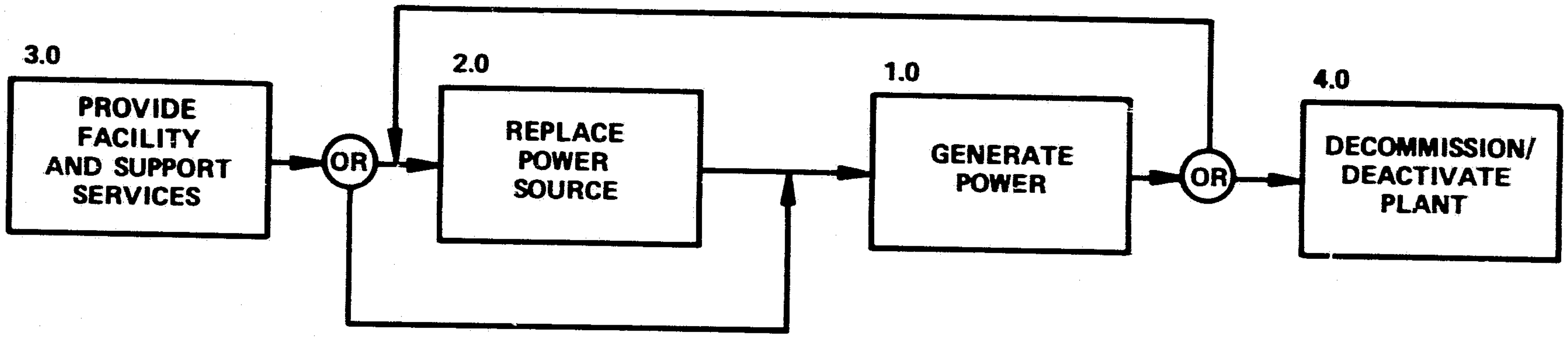


Figure 1.3-3. Rotating Equipment Configurations



DESCRIPTION OF FUNCTIONS:

3.0
- PROVIDE POWER INTEGRATION WITH GRID –
- REGULATE AND DISTRIBUTE POWER –
- MONITOR AND CONTROL –
- PROVIDE SERVICES TO PAFC SYS. AND FACILITY

2.0
- PROVIDE POWER GENERATOR SYS. REPLACEMENT – (NEW OR REPOWERING OF INPLACE FACILITY)

1.0
- PROVIDE REACTANTS –
- PROVIDE POWER REMOVAL –
- PROVIDE WASTE REMOVAL –
- PROVIDE CONTROL RESPONSE CAPABILITY –
- GENERATE POWER –

Figure 1.3-4. PAFC Power Plant Top Level Reference Functional Flow Diagram

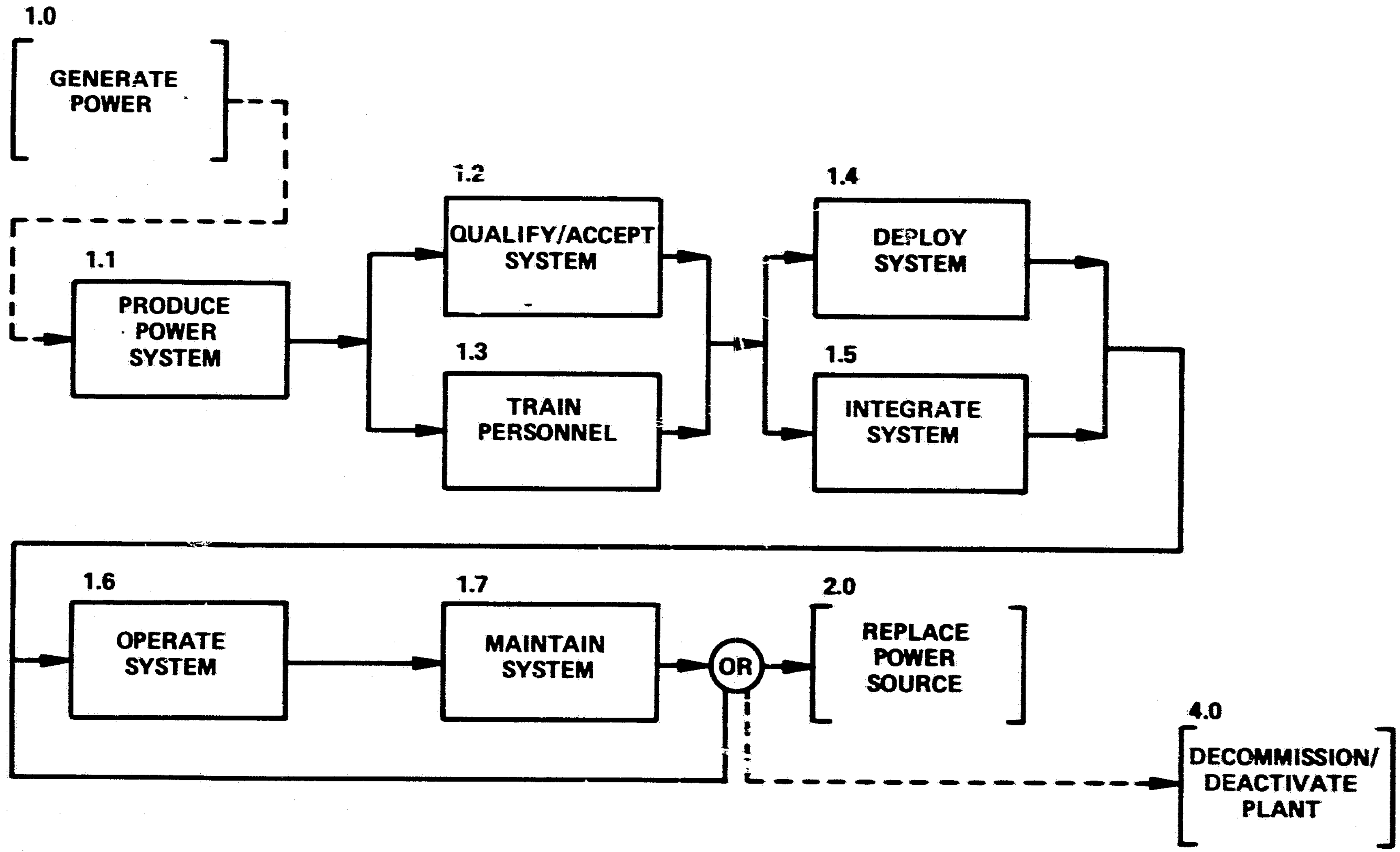


Figure 1.3-5. Top Level Functional Flow Diagram PAFC Power Generation

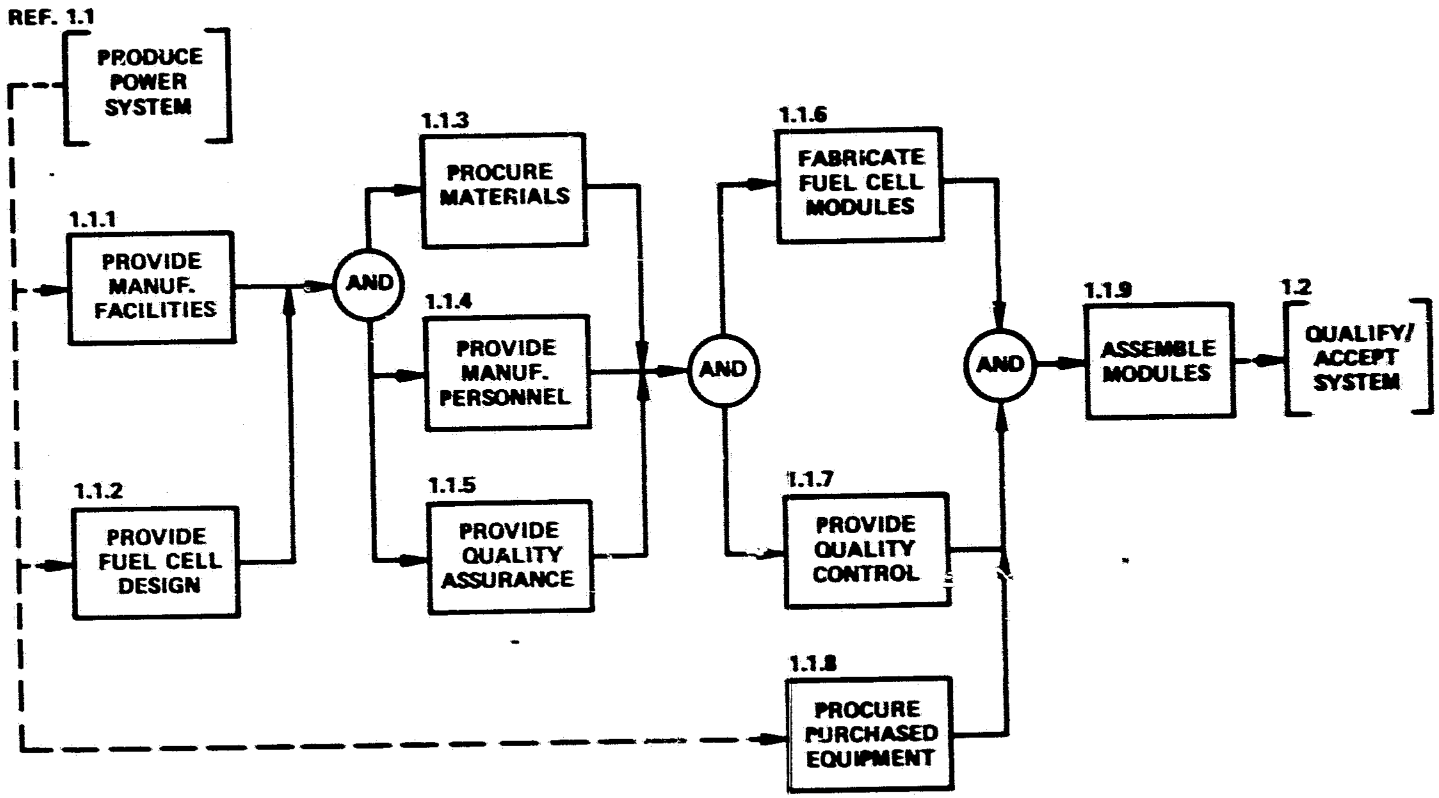


Figure 1.3-6. Functional Flow Diagram - 1st Level Functions - Produce Power System

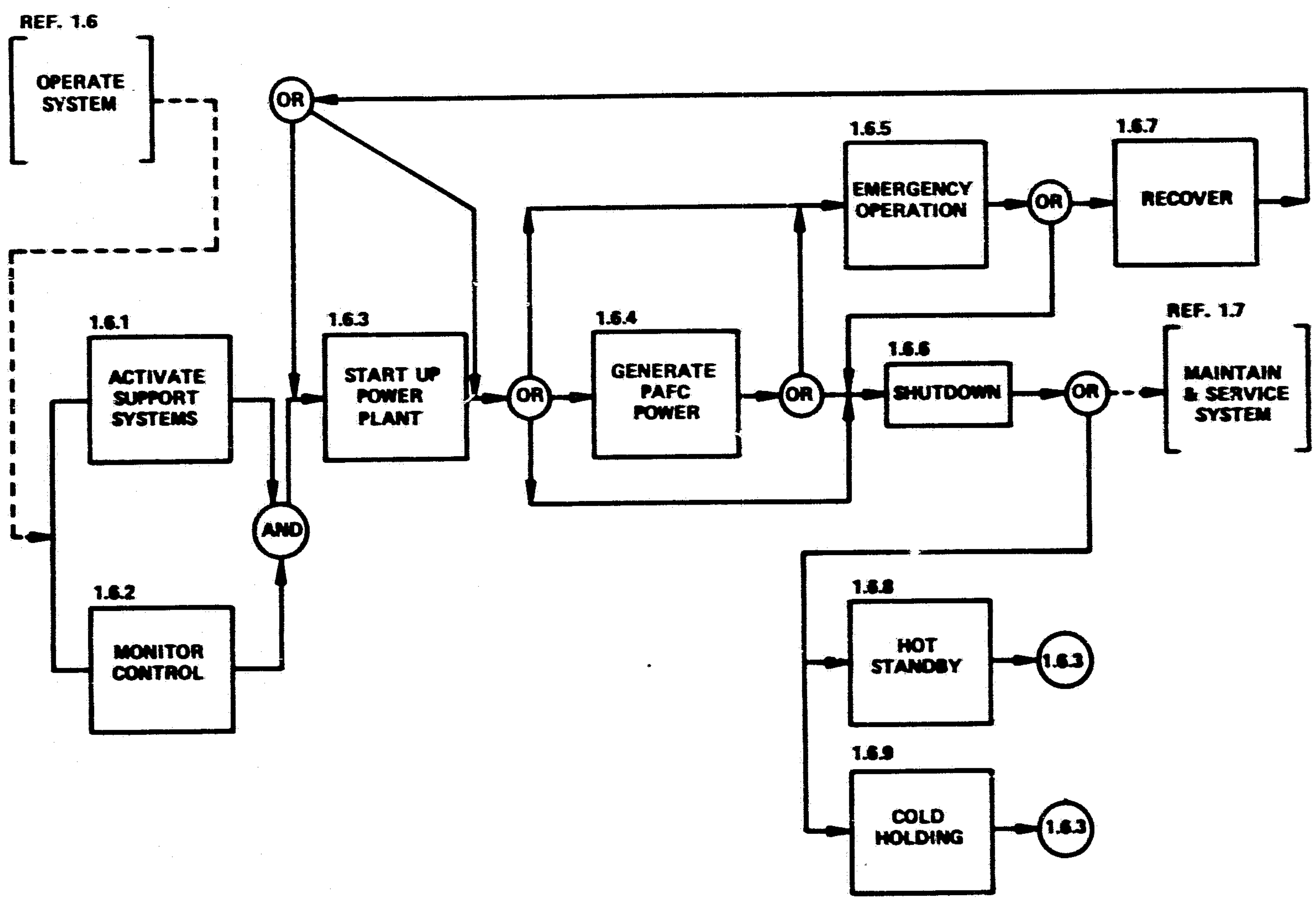


Figure 1.3-7. Functional Flow Diagram - 1st Level Function - PAFC Generator Operation

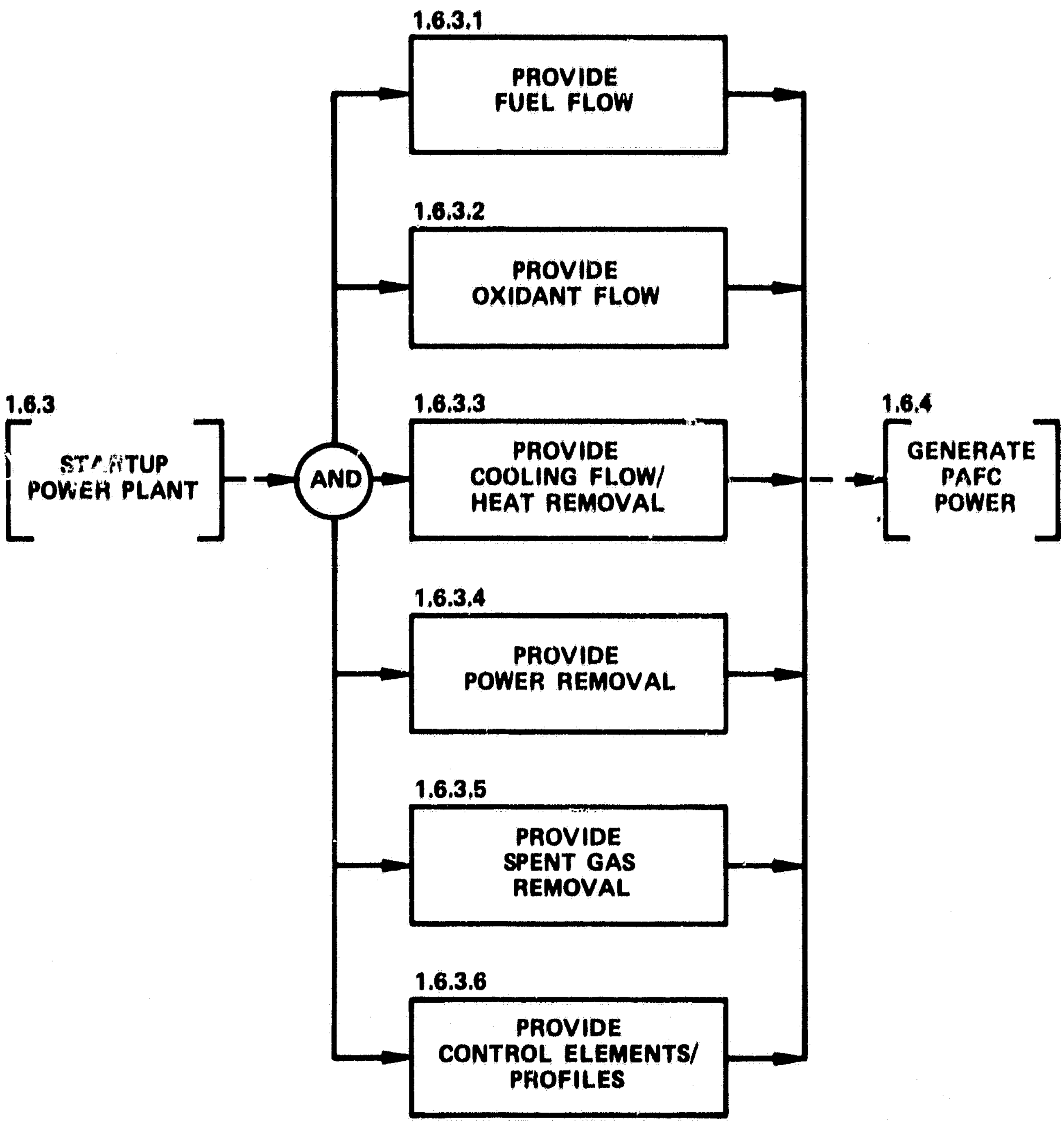


Figure 1.3-8. Functional Flow Diagram - 2nd Level - Power Plant Startup

TABLE 1.3-2. REQUIREMENTS ALLOCATION FUEL CELL MODULES

Requirements Allocation Sheet	Functional Diagram Title and No. 1.0 GENERATOR POWER		
Function Name and Number	**Design Requirements***	**Facility Requirements**	
1.1 Produce Power	1. Provide air-cooled PAFC capable of producing 7.5 MW_e DC power from reformed H_2-rich gas and air. 2. PAFC design shall be air-cooled and of the "zee" and "treed" type. 3. Rated operating conditions shall be: Pressure = 3.4 atm Temperature = 190°C (average) (tbd) (tbd) Cell Voltage = (tbd) Current Density = (tbd) H_2 Utilization = 80% (minimum) 90% (maximum) O_2 Utilization = 50% (at rated load) Environmental conditions per Table TBD . 4. Power Output = 7.5 MW_e (nominal) Maximum Overload = 10% at rated load for (tbd) maximum Voltage output = 2000 VDC (min. at rated load) Operating Range = 25-100% rated power Power quality per Table TBD . Anode gas composition per Table TBD .		

*
- Purpose of the function
- Parameters of design
- Requirements that constrain the design
- Requirements for system effectiveness

TABLE 1.3-2. REQUIREMENTS ALLOCATION FUEL CELL MODULES (Continued)

Requirements Allocation Sheet	Functional Diagram Title and No. 1.0 GENERATOR POWER		
Function Name and Number	**Design Requirements***	**Facility Requirements**	
1.1 Produce Power (Continued)	5. Fuel cell heat rate $\leq 7730 \frac{Btu}{kW\text{-}hr}$ (at rated load) Operating lifetime ≥30,000 hours Maximum module size must be truck transportable per Table __TBD__. System availability ≥ 98% Transient response = (tbd) 6. Design codes and standards for local, state, and federal per Table _TBD_ shall be adhered to. Safety design requirements per Table _TBD_. Institutional and regulatory requirements per Table _TBD_.		

* • Purpose of the function
• Parameters of design
• Requirements that constrain the design
• Requirements for system effectiveness

related experience. These procedures and the previously reported as being completed process procedures were used to manufacture and assemble the components for a 23 cell stack, essentially identical to Stack 561, to demonstrate the state-of-the-art technology transfer from ERC to Westinghouse.

All sub-assembly and assembly operations associated with the first Westinghouse 23-cell stack (designated as DG-001) were completed including stack compression. The required instrumentation was installed and the process manifolds, provided by ERC, were attached. Open circuit voltage (OCV) tests were performed, the results of which are shown on Table 2.2-1. As can be seen, all cell OCV's exceed the established 750 mV acceptance criteria except for cell No. 14.

Manufacturing activities were initiated to fabricate components for a second 23-cell stack (Mark II design) that is essentially identical to Stack 564. The required blanks for the "zee" bipolar and "treed" cooling plates were molded and machining of these plates was completed. This stack will demonstrate the state-of-the-art technology transfer from ERC to Westinghouse relative to the baseline Mark II fuel cell design configuration.

Twenty-two (22) 12 inch x 17 inch flat plates were molded for materials characterization performed in Subtask 3.8. These plates were used for 2 inch x 2 inch (2 x 2) bipolar plates. Also, the die plate for 2 x 2 bipolar plates was received from a vendor and will be used in the future to mold this size plate rather than machining.

TASK 3: STACK TESTING

3.8 Materials Testing

Raw Materials Characterization

The survey of raw materials suppliers was completed and all suppliers contacted responded to our inquiries. The replies were either quite detailed or consisted of only a product specification giving typical properties. The results of this effort are summarized in Table 3.8-1. Based on this information, ten (10) draft raw material specifications were prepared and are currently being reviewed internally prior to submittal to suppliers for their review and comments.

TABLE 2.2-1. INITIAL OCV TEST FOR STACK DG-001

Date: December 23, 1981 Stack Temperature: 292^{o}F

CELL VOLTAGE (mV)

CELL NO.	H_2 ON AIR ON	H_2 ON AIR OFF	H_2 ON AIR OFF (1 MINUTE)	H_2 OFF AIR ON	H_2 OFF AIR ON (1 MINUTE)	H_2 OFF AIR OFF	H_2 OFF AIR OFF (1 MINUTE)
1	917	917	914	918	918	918	913
2	864	864	855	864	863	863	854
3	917	917	914	918	918	919	916
4	873	872	866	872	871	870	865
5	904	902	898	901	901	901	896
6	883	882	875	880	879	877	869
7	908	907	903	906	906	905	900
8	926	926	923	926	926	926	923
9	906	906	902	904	903	902	898
10	922	920	916	918	918	907	891
11	889	888	883	886	884	882	876
12	906	906	902	904	904	903	895
13	920	920	914	922	921	921	912
14	745	731	528	759	756	744	482
15	925	925	920	922	918	900	884
16	913	913	908	914	914	914	909
17	892	891	885	890	889	888	881
18	932	932	930	934	934	934	931
19	913	912	909	912	912	910	906
20	916	914	911	908	905	900	894
21	935	934	931	934	933	932	928
22	919	919	914	918	917	916	911
23	914	914	911	917	917	918	914
TOTAL	20739	20712	20412	20727	20707	20650	20248
Average	902	901	887	901	900	898	880
Std. Dev.	39	41	81	36	37	38	89

TABLE 3.8-1. FUEL CELL RAW MATERIAL VENDOR INQUIRY STATUS SUMMARY

SUPPLIER	RAW MATERIAL	VENDOR SUPPLIED		COMMENT	DRAFT SPEC WRITTEN
		PROCESS SPECIFICATION	PRODUCT SPEC. BULLETIN		
Carborundum	1000 grit green SiC	Yes			Yes
DuPont	Teflon 6C Teflon 30 Teflon 120	No No No	Yes Yes Yes		Yes Yes Yes
Reichhold Chemical, Inc.	29-703 Varcum	No	Yes		Yes
Asbury Graphite Mills, Inc.	A99 graphite powder	No	No	Supplied typical analysis	Yes
Stackpole	PC-206 graphite paper	No	No	Indicated few internal controls enforced	Yes
Cabot Corporation	Vulcan XC-72	No	Yes		Yes
Guard-All Chemical Co., Inc.	Shell Sol 340	No	Yes		Yes
Johnson-Matthey, Inc.	Type ERC catalyst 10 wt. percent Pt on Vulcan XC-72 carbon black	No	Yes	Specific limits supplied	Yes

Chemical analyses were conducted on selected raw materials and the results are presented in Tables 3.8-2, 3.8-3 and 3.8-4. The levels of the residual elements present are in general agreement with vendor data. However, the high sulfur level present in Vulcan XC-72 carbon black will be discussed with the vendor to establish whether this level is expected to be typical. The spectrochemical analysis of the various Teflons used and the 29-703 resin indicate very low levels of residual elements, and thus the requirement for chemical analysis was depleted from the specifications for these materials.

Apparent densities of the powder raw materials was measured using the Scott Volumeter technique, ASTM Procedure B329-76, and the results are given in Table 3.8-5. Screen analysis (particle size distribution) was attempted on the A99 graphite powder and the 29-703 resin. Since the powders are not free-flowing and bridge the screen openings, very little powder passed through a 100 mesh screen. Wet screen analysis of the A99 powder using water as the fluid media was performed. Results indicate a plus 325 mesh of 2.48 wt. percent, which is approximately 1 percent greater than the typical vendor analysis for this powder.

Particle shape and character of the ground A99 graphite powder were examined using conventional light microscopy. The particle shape was a combination of flake and needle geometries, predominantly needle, consistent with a material ground or milled from a highly graphitic bulk starting material. The needle particle shape accounts for the relatively large orientation or anisotropy in such properties as electrical resistivity noted in plates pressed from this material. This metallography revealed the presence of a small number of sliver or needle-shaped metallic inclusions in the graphite powder. These particles are most likely introduced during the grinding or milling operation and account for part of the relatively high iron noted in the spectrographic analysis of this powder. Scanning electron microscopy of the metallic inclusions confirmed their high iron content.

TABLE 3.8-2. EMISSION SPECTROGRAPHIC ANALYSIS RESULTS ON SELECTED RAW MATERIALS AND REPEATING CELL COMPONENTS, VALUES IN WT. %

MATERIAL OR COMPONENT	Al	Ag	B	Ba	Be	Bi	Ca	Cd	Co	Cr	Cu	Fe	Ga	Ge
A99 Graphite	0.02	<0.0003	0.0006	0.002	<0.0001	<0.001	0.03	<0.03	0.001	0.03	0.002	0.2	<0.001	<0.0003
XC-72	0.01	<0.0003	<0.0001	0.002	<0.0001	<0.001	0.03	<0.03	<0.001	<0.0003	0.0001	0.003	<0.001	<0.0003
Plate 102	0.03	<0.0003	0.0001	0.002	<0.0001	0.001	0.03	<0.03	0.001	0.03	0.003	0.2	<0.001	<0.0003
Plate 141	0.02	<0.0003	0.0001	0.002	<0.0001	0.001	0.03	<0.03	0.001	0.02	0.003	0.2	<0.001	<0.0003
Carbon PC 206	0.002	<0.0003	0.0003	0.002	<0.0001	<0.001	0.01	<0.01	<0.001	<0.0003	0.0002	0.003	<0.001	<0.0003
Matrix 008-8	0.02	<0.0001	0.0001	0.001	<0.0001	<0.0003	0.04	<0.01	0.0007	0.001	0.0004	0.007	<0.0004	<0.0001
Silicon Carbide	0.005	<0.0005	<0.001	<0.001	<0.0005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0005	<0.004	<0.001	<0.002
	K	La	Li	Mg	Mn	Mo	Na	Nb	Ni	P	Pb	Sb	Si	Sn
	0.003	-	<0.0003	0.003	0.002	0.001	0.001	<0.003	0.006	<0.01	0.002	<0.002	0.03	<0.001
	0.003	-	<0.0003	0.01	<0.0001	<0.0001	0.07	<0.003	<0.001	<0.01	<0.001	<0.002	0.02	<0.001
	0.002	-	<0.0003	0.01	0.002	0.002	0.001	<0.003	0.008	<0.01	0.002	<0.002	0.03	<0.001
	0.003	-	<0.0003	0.006	0.002	0.001	0.002	<0.003	0.008	<0.01	0.001	<0.002	0.03	<0.001
	0.002	-	<0.0003	0.0001	<0.0001	0.0004	0.0003	<0.003	<0.001	<0.01	<0.001	<0.002	0.007	<0.001
	0.007	-	<0.0002	0.2	0.0004	<0.0001	0.03	<0.001	0.0004	<0.004	0.0004	<0.0007	0.004	<0.0004
	<0.001	-	<0.001	0.0005	<0.001	<0.001	<0.001	<0.03	0.001	-	<0.001	<0.01	Major	<0.001
	Sr	Ti	V	W	Zn	Zr								
	0.0008	0.01	0.002	-	0.001	0.002								
	0.001	0.001	<0.0003	-	<0.001	<0.001								
	0.001	0.007	0.002	-	0.06	0.002								
	0.001	0.007	0.002	-	<0.001	0.001								
	0.0008	0.005	0.01	-	0.001	<0.001								
	0.0007	0.001	0.0001	-	0.0004	<0.0004								
	<0.005	0.03	0.01	-	<0.001	0.02								

TABLE 3.8-3. SPECTROCHEMICAL ANALYSIS OF TEFLONS AND 29-703 RESIN USED IN REPEATING CELL COMPONENTS, VALUES ARE GIVEN AS PARTS PER MILLION

SAMPLE / ELEMENT	Al	Ag	B	Ba	Be	Bi	Ca	Cd	Co	Cr	Cu	Fe	Ga	Ge
Teflon 6	<3	<3	<3	-	<3	<3	<3	-	<3	<3	<3	<3	-	<3
Teflon 30	3	<3	<3	-	<3	<3	<3	-	<3	<3	<3	5	-	<3
Teflon 120	3	<3	3	-	<3	<3	<3	-	<3	<3	3	5	-	<3
Resin 29-703	<3	<3	<3	-	<3	<3	3	-	<3	10	<3	25	-	<3
	K	La	Li	Mg	Mn	Mo	Na	Nb	Ni	P	Pb	Sb	Si	Sn
Teflon 6	-	-	-	<3	<3	<3	<5	-	<3	-	<3	<3	3	<3
Teflon 30	-	-	-	<3	<3	<3	20	-	<3	-	<3	<3	25	<3
Teflon 120	-	-	-	<3	<3	<3	20	-	<3	-	<3	<3	25	<3
Resin 29-703	-	-	-	3	<3	3	20	-	10	-	<3	<3	>50	<3
	Sr	Ti	V	W	Zn	Zr								
Teflon 6	-	<3	<3	-	<3	<3								
Teflon 30	-	<3	<3	-	<3	<3								
Teflon 120	-	<3	<3	-	<3	<3								
Resin 29-703	-	<3	3	-	3	<3								

TABLE 3.8-4. SULFUR ANALYSIS OF CARBON MATERIALS USED IN REPEATING CELL COMPONENTS

MATERIAL	WT. PERCENT SULFUR
Vulcan XC-72	1.63
A99 Graphite Powder	0.045
PC-206 Backing Paper	0.034

TABLE 3.8-5. SCOTT DENSITIES OF POWDER RAW MATERIALS USED IN REPEATING CELL COMPONENTS

POWDER	VENDOR	IDENTIFICATION	APPARENT DENSITY
A99 Graphite	Asbury	317-17-5	0.308 g/cc
A99 Graphite	Asbury	317-17-6	0.321 g/cc
A99 Graphite	Asbury	317-17-7	0.306 g/cc
Resin 29-703	Reichhold	-	0.218 g/cc
Silicon Carbide (1000 grit)	Union Carbide	-	0.619 g/cc

TABLE 3.8-6. SOLIDS CONTENT OF TEFLON AQUEOUS DISPERSION

MATERIAL	VENDOR	LOT NO.	SOLIDS REPORTED	CONTENT WT. % MEASURED
Teflon 30	DuPont	9088	61.5	56.5
Teflon 120	Dupont	9376	55.2	55.9

Solids content of Teflon 30 and 120 was determined and the results are given in Table 3.8-6. The low solids content determined for the Teflon 30 is attributed to inadequate mixing before sampling. This will be resampled after a more thorough mixing.

Test apparatus (Varcum Test Procedure VTP-11-6-1) was set up to measure the inclined plate flow of the 29-703 resin. The flow lengths measured at 125°C for two samples were 102 and 99 mm compared to the vendor typical range of from 75 to 90 mm.

A procedure for electrolyte preparation (acid concentration) was written and approximately 2 liters of acid was prepared for utilization in the 23-cell stack (DG-001) fabricated at AESD during this quarter.

Fuel Cell Component Characterization

Characterization of the typical 12 x 17 DIGAS bipolar plates (67 wt. % graphite, 33 wt. % resin) for use in stack DG-001 was completed. Density of as-pressed and heat-treated plates was determined on a limited number of samples. The density as pressed was 1.74 g/cc and after heat treatment at 950°C increased slightly to 1.79 g/cc. The carbon yield from the 29-703 resin was calculated for heat-treated plates and ranged from 62 to 65 percent. This carbon yield is higher than the 50 percent value indicated by TGA analysis reported by ERC and maybe partially associated with the slower heating rates utilized for plate heat-treatment. The chemistry and kinetics of pyrolysis of hydrocarbons are complex and data is lacking to explain all possible interactions of the process. A general discussion of the complexity is given by E. Fitzer, et al.*

Flatness of the DIGAS plates before and after heat-treatment was determined; as-pressed the plates exhibit a saddle shape with an out-of-flatness of from 0.18 to 0.30 cm in the long direction. After heat treatment, this increases to approximately

*E. Fitzer, K. Uueller and W. Schaffer, "The Chemistry of the Pyrolytic Conversion of Organic Compounds to Carbon," in Chemistry and Physics of Carbon, Vol. 7, Uarsel Dekker Inc., New York, p. 237-383.

0.51 cm even though the plates are shimmed stacked flat and weighted during the heat treat cycle. In addition, the plates were slightly "hour glass" in shape; i.e., the width and length measured at the center was less than the edge width or length.

Spectrographic analysis results of the reference composition DIGAS plates and plates made with an internal mold release (2 wt. percent zinc stearate) are given in Table 3.8-2. The results are those that would be expected from the raw material analysis presented in this table and Table 3.8-3. The zinc level (internal mold release plate) after heat treatment was 0.06 wt. percent. The effect of possible acid disolution and contamination of the cell by this residual zinc must be established before such a release agent can be adapted for use in component production.

Conventional light microscopy and scanning electron microscopy of as-pressed and as heat-treated plates were completed. Porosity and metallic inclusions were observed in plates in both conditions. While the pore size and distribution remains to be quantified, the inclusions were the same as those described earlier in the A99 graphite powder.

Characterization of a series of flat plates to be machined into final geometries for future stacks was initiated and as-pressed plates in the following nominal thicknesses were obtained: 0.34, 0.43, 0.53 and 0.64 cm. These will be characterized in the as-pressed and heat-treated conditions.

Electrical resistivity of samples cut from flat heat-treated plates was measured (plate thickness was 0.180 inch). The use of flat plates for this measurement was necessitated due to the irregular geometry of the DIGAS plate. The average resistivity perpendicular to the pressing direction was 1.71 mΩ-cm and parallel to the pressing direction it was 5.99 mΩ-cm, a ratio of 3.5:1. This anisotropy is expected due to the flake geometry of the A99 graphite powder used.

The pore size distribution and pore volume of the electrodes and MAT-1 matrix were determined from ercury intrusion porosimetry data and are given in Table 3.8-7. Teflon impregnation of the PC-206 backing paper (approximately 40 wt. percent Teflon) reduces the total porosity of the backing paper from 83.3 percent to 62.4 percent and the pore volume from 2.37 to 1.12 cm^3/g. From the measured bulk densities and internal pore areas, both by mercury intrusion, the calculated mean pore diameters of the laminated backing paper and anode catalyst layer were 1566 and 372 Å, respectively. Based on these intrusion studies, further studies were conducted to determine the effects of diffusion resistance in the porous structure on subscale cell performance. Oxygen partial pressure drops in the laminated structure are highly dependent on the current density and air flow rates. At 300 mA/cm^2 and 1.6 stoich, for example, the calculated oxygen partial pressure drop across the backing paper is approximately 22 percent. This pressure drop in turn results in a loss of about 14 mV in the achievable cell voltage.

The as-measured density of the silicon carbide layer applied to the cathode was determined to be approximately 1.32 g/cc. Assuming a density of 3.20 g/cc for the silicon carbide, the calculated SiC layer porosity was 58.8 percent. Using 100 wt. percent H_3PO_4 at 191°C and an exposure time of seven days, it was determined that the SiC layer and the cathode catalyst layer absorb approximately 0.0823 grams of electrolyte per square centimeter of electrode area.

The density of a typical AESD-produced MAT-1 matrix was determined to be 0.459 g/cc based on weight and dimensional measurements. The mercury intrusion bulk density of 0.424 g/cc is in relatively good agreement with this value. The spectrographic analysis of a typical matrix is given in Table 3.8-2.

The catalyst loading was checked by wet chemistry for a typical anode and found to be 0.31 mg Pt./square centimeter. The calculated loading of this anode based on the mixed weight of catalyst and Teflon and final rolled thickness was 0.34 mg/cm^2.

TABLE 3.8-7. INTRUSION DATA FOR AESD-MANUFACTURED FUEL CELL COMPONENTS

PHYSICAL PROPERTIES	PC-206 BACKING PAPER*(1)	BACKING PAPER (C014-BP)(1)	ANODE CATALYST LAYER (A015-CL)(1)	MATRIX (MAT-1)(2)
(1) Porosity, %	89.3	62.4	70.2	--
(2) Mean Pore Diameter, Å	1419	1566	372	300
(3) Bulk Density, g/cc	0.377	0.557	0.560	--
(4) Pore Volume, cc/g	2.37	1.12	1.25	1.60
(5) Pore Area, m^2/g	66.8	28.6	134.4	224.7

*Intrusion data from the supplier are porosity = 82.4% and bulk density = 0.366 g/cc.

(1) Results from Westinghouse Research and Development Center.

(2) Preliminary data from Particle Data Laboratories, Inc.

A small test apparatus was built to investigate phosphoric acid corrosion resistance of materials at 400^{o}F without applied potential. The initial investigation now running will provide qualitative data on the acid resistance of two candidate insulator materials - Haysite and Micarta G-11.

Planning of a manifold seal test and test fixture, both material and seal geometry, was initiated and is being coordinated with design requirements for the 10 kW stack design. Inquiries were made to potential seal material vendors and flat graphite/resin plates were pressed and await heat treatment for use in these tests.

Subscale Fuel Cell Functional Performance Testing

Assembly and system checkout of the unpressurized 25-stand subscale (2 inch x 2 inch) test facility was completed. All safety systems were completed and their functional performance verified. A checkout cell was assembled from AESD-produced electrode components and put on test late in December. The terminal voltage of this cell is approximately 0.600 volts at 200 mA/cm^2 at 177°C.

This test facility was modified to provide a facility for conducting the open circuit voltage and cross-leak evaluation of the AESD-produced 23-cell stack, DG-001. The data from these tests are reported elsewhere in this report.

The machining of 25 sets of graphite/resin end plates for 2-inch x 2-inch cells was completed, and they are currently awaiting heat treatment. These plates were machined from 0.210 inch thick plates. Several sets of 2-inch x 2-inch end plates with as-pressed process gas groves were also made. These will be heat treated with the machined plates to examine the feasibility of this approach to producing the required hardware.

Subscale Cell Test No. 17 is still in progress. This cell, built from AESD-produced electrodes and matrix has been run for over 1500 hr at 191°C and 200 mA/cm^2. The highest terminal voltage reached was 0.655 volts after about 900 hr. At 177°C, the terminal voltage was 0.635 volts at 200 mA/cm^2.

After completing 1000 hours of operation, Cell Test No. 17 was utilized to investigate the effect of process air flow rates on cell performance, Figure 3.8-1 shows the variation of cathode voltage with air flow rate expressed as stoichs, which is the reciprocal of oxygen utilization. A significant potential drop on the air electrode was observed as the air flow was reduced to below 2 stoich. At 300 mA/cm^2, for example, the reduction of flow rate from 7 to 1.2 stoich resulted in a voltage decrease of about 84 mV. Further theoretical considerations indicated that the potential losses at the low flow rates were mainly due to an increase in either diffusion or activation overpotentials or both.

The investigation of oxygen partial pressure influence on the cathode performance was also initiated using Cell No. 17. Preliminary results indicate that using N_2-O_2 gas mixtures containing 35 percent and 49 percent oxygen, the achievable cell potential at 200 mA/cm^2 and 5 stoich air increased by approximately 30 and 50 mV, respectively when compared to air. This test cell will continue to be used for process gas flow studies.

TASK 5: MANAGEMENT REPORTING AND DOCUMENTATION

5.1 Supervision and Coordination

Technical and programmatic direction for conducting, integrating, controlling and documenting the project was provided. Coordination of efforts among the various cognizant department personnel was continued. Various informal working meetings or sessions and project review meetings were held for purposes of control, review, and progress assessment.

The design features of the 10 kW 44-cell stack, "zee" bipolar plate, and "treed" cooling plate were selected and presented in a review meeting with the NASA Project Manager on December 10 and 11, 1981. The stack design requirements, test objectives, measurement requirements, and design configuration presented to the NASA Project Manager reflected inputs from Westinghouse R&D Center and ERC personnel.

The coordination of this project with ERC programs DEN3-201 and DEN3-205 was continued.

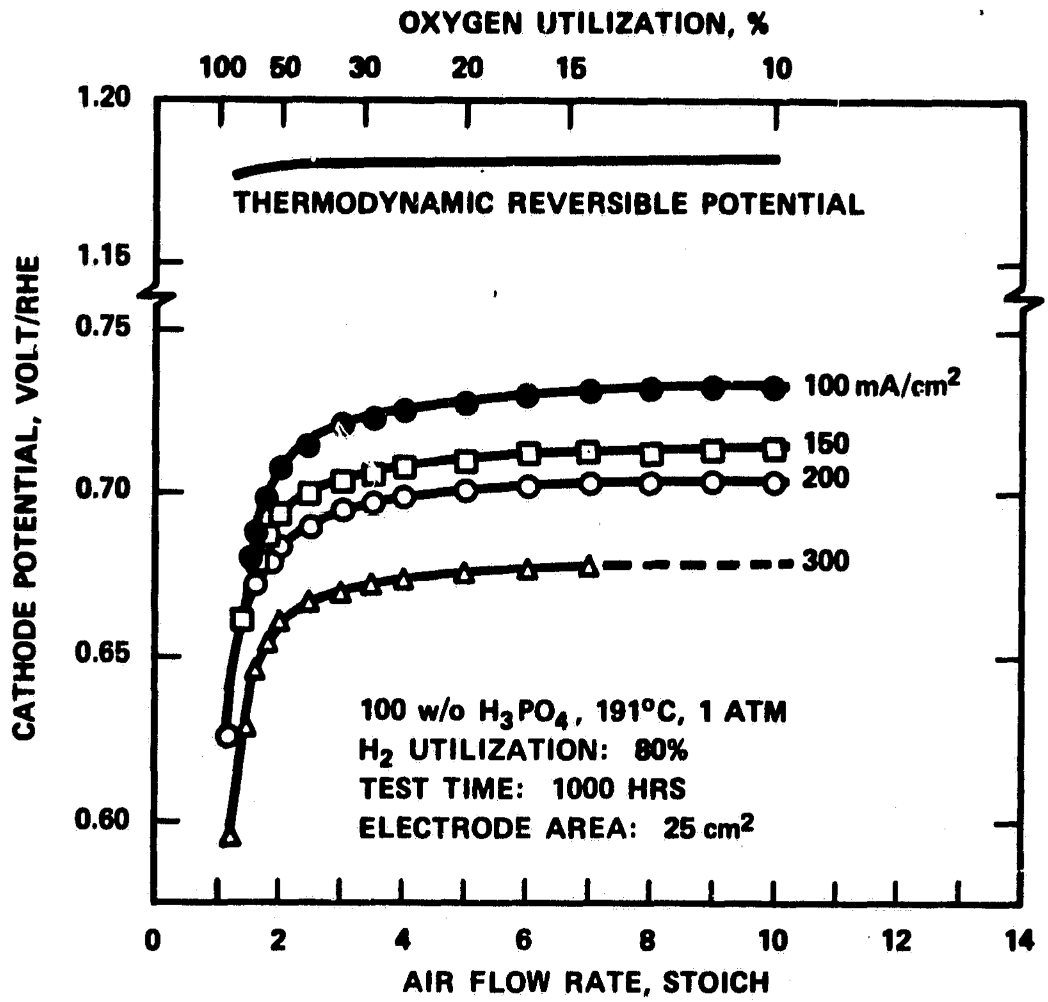


Figure 3.8-1. Variation of Cathode Voltage With Air Flow Rate for Test Cell No. 17

5.2 Documentation and Reporting

The Technical Progress Narrative Reports for October and November, 1981 prepared and submitted for NASA patent approval. Also, financial management (NASA Form 533M) and Performance Analysis (NASA Form 533P) reports were prepared and submitted for each of the above mentioned periods. The Quarterly Contractor Financial Management (NASA Form 533Q) report for the period beginning January 1, 1982 was prepared and submitted.

The patent approved Monthly Technical Progress Narrative Reports for July thru November, 1981 inclusive were distributed in accordance with the NASA provided distribution list.

The Quarterly Technical Progress Narrative Report for the period July 15 thru September 30, 1981 was prepared and submitted to the NASA Project Manager for approval.

Various contract required deliverable items of documentation were submitted to the NASA Project Manager. These included: (1) PAFC Technical Constraints Report, (2) PAFC System Trade Study Reports, (3) 10 kW Stack Preliminary Design Drawings, and (4) Bipolar and Cooling Plate Final Design Drawings.

Weekly and monthly technical highlights were reported to the NASA Project Manager.

III. PROBLEMS

There are no technical or schedule problems.

IV. WORK PLANNED

TASK 1: DESIGN OF LARGE CELL STACKS

Detail design of the identified 10 kW stack long lead components will be continued and completed. The designs will be released to obtain competitive vendor time and cost quotations.

Various trade studies and analyses will be completed and submitted to the NASA Project Manager. These include: (1) System Level Trade Study reports for power level, pressure, and temperature at rated design point, and power level control method, (2) Fuel Processing System Technology Assessment, (3) Plant Functional Analysis, and (4) Cost of Energy Analysis.

TASK 2: STACK FABRICATION

Initiate and complete performance testing of the 23 cell stack DG-001 (Stack 561 configuration).

Initiate the manufacture of the non-repeating components for the 23 cell stack (Stack 564 configuration) such as compression plates, Haysite insulators, and copper collectors and the repeating components. Also, procure the stack manifold materials.

Continue to provide fuel cell repeating components for characterization performed in Task 3.

TASK 3: STACK TESTING

Internal review of the ten (10) draft raw material specifications will be completed and issued to NASA and the appropriate raw material vendors for review and comment.

Repeating fuel cell component characterization will be continued.

A draft procedure for subscale 2-inch x 2-inch fuel cell assembly and checkout will be prepared. A process for molding 2-inch x 2-inch plates will be developed.

Heat treatment of 15 sets of graphite/resin end plates for use in 2-inch x 2-inch tests will be initiated.

TASK 5: MANAGEMENT REPORTING AND DOCUMENTATION

The required technical and programmatic direction for conducting, integrating, coordinating, controlling, and documenting the OS/IES Program will be provided. Bi-monthly status review meetings will be convened to review the schedular status of each subtask.

The Monthly Financial Management (NASA Forms 533M & P) and Technical Progress Narrative Reports will be prepared and submitted to the NASA LeRC Project Manager. Preparation of the Quarterly Technical Progress Narrative and Final Technical Reports will be initiated and completed.

A number of technical reports will be submitted next quarter. These reports include: (1) System Trade Studies, (2) System/Subsystem Functional Analysis, (3) Cost of Energy Analysis, (4) Preliminary Cell Raw Materials Specification, (5) Fuel Processing System Assessment, and (6) Detail Design Drawings of various 10 kW Stack Long Lead Components.